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Investigation of Permanent Deformation in Iraqi Highways- Iraqi Expressway No.1 as a Case Study

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A B S T R A C T

Pavement rutting as a permanent deformation is a major type of distress in flexible pavements. In Iraq, the rutting in expressway pavements represents a severe problem due to its widespread, and high severity and distress density levels. Therefore, driving is profoundly dangerous and causes severe damage to the vehicles' parts and the life of its riders. The current research studies the major mechanisms responsible for rutting and evaluates the structure of the Iraqi Expressway No.1 at selected sections. The work encompasses field and laboratory aspects. The field work involved; performing field surveys to investigate the pavement rutting condition and its extension with depth, characterizing pavement layers in terms of geometric material properties, and collecting field samples for lab tests. The laboratory work was detailed and included; performing a set of standard lab tests on samples taken from the asphalt, the subbase, and the subgrade layers and natural ground. In addition, the project's archive was searched for specific design information and limitations. In order to assess pavement rutting in the selected sections of Expressway No.1/R9 (A and B), two well-established evaluators were considered; the rutting severity levels and the distress density.

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1. Introduction

Rutting typically occurs in asphalt layers and/or underlying unbound layers, forming one of the main pavement distress modes. In flexible pavement where water cannot penetrate the unbound layers, about (85-95) % of the rutting accumulates in the asphaltic layers (Du et al, 2018). Rutting appears as a groove in pavement parallel to the wheel paths (Li et al, 2021). Particularly in highway entrances, checkpoints, bus stations, and intersections, horizontal loading applied via tire-pavement friction due to repeated braking of the vehicles (especially heavy vehicles) and the impact of acceleration frequently causes large shear stress and strain in pavement structure (Li et al, 2013). In highways with long and/or steep sectors, rutting can easily occur according to the time-temperature superposition fundamentals (Li et al, 2015). The rutting performance is greatly affected by weather and traffic conditions including traffic densities, heavy loading, slow traffic movements, and elevated temperatures (Morea et al, 2011). Furthermore, using aggregates or asphalt binders with poor quality can increase the rutting susceptibility (Zhang et al, 2017; Zhang et al, 2018). In addition to its direct effects, rutting can cause problems such as deterioration of pavement structure due to the penetration of water accumulated in the ruts (Tian et al, 2017). Moreover, the accumulated water may cause skid hazards that lead to traffic accidents (Wang et al, 2012).

In Iraq, the rutting of highway pavements represents a severe problem due to the widespread of this type of pavement distress on most expressways, and the high severity and density levels of rutting due to many reasons

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such as environmental effects, uncontrolled heavy trucks, and the poor construction. In many cases, the rutting takes severe, profound, and dangerous levels due to its uneven and non-uniform shapes and extensions, especially when combined with other distresses such as waving, corrugation, and batching (Khaleefah, 2019). In such sections, driving is very dangerous and causes severe damage to the vehicles' parts. Such severe rutting levels can be found near, or at checkpoints, entrances, intersections, and other highway sections where the traffic density is high and the speed is close to zero. In these cases, the time of load application on pavements is long compared to that at other sections with higher driving speeds. A longer time of load application increases the stress on pavement layers, thereby increasing the chances of rutting occurrence and increasing its severity level (Hameed, 2021). The hot weather of Iraq, most of the year, makes the situation even worse by increasing the rutting susceptibility of the asphaltic pavement layers.

The research in this domain is still limited and, most often, adopts laboratory approaches that tend to ignore field conditions. The present work studies rutting of the Expressway No.1 by combining numerous filed aspects related to the existing pavement structure.

2. Research Methodology

2.1 Authorization

To conduct the field part of the work, the researchers had to coordinate with many governmental institutions within Anbar and Baghdad provinces, including;

- Ministry of Construction, Housing, and Public Municipalities (MCHPM)/ Roads and Bridges Department (DRB).
- Expressway Directorate (DE).
- Ramadi Maintenance Center for Expressway (MCER).
- Anbar Province and Directorate of Roads and Bridges of Anbar (DRBA).
- Command of Anbar Operations.
- Directorate of Anbar Police.

2.2 The Field Survey of Expressway No.1

Fortunately, the researchers were able to coordinate the fieldwork of the research with the ongoing maintenance works by DRB. This maintenance included the restoration of overpasses, underpasses, pipe and siphon culverts, and box culverts. The researcher took the advantage that the expressway was partly closed to complete the field survey.

2.3 Description of Study Area

Expressway No.1 in Iraq is one of the important and strategic projects that were constructed four decades ago. This Expressway connects Iraq with the neighboring countries Jordan, Syria, and Kuwait with a length (including interchanges length) of about 1250 km. Another 90 km represents the total roads linking with the provincial centers Ramadi, Baghdad, Hilla, Diwaniyah, Samawah and Nasiriya. The Expressway runs through Iraq's governorates of Al Anbar, Baghdad, Babel, Al Qadisiya, Al Muthanna, Dhi Qar, and Basra, as shown in Figure 1. A contract for studying, preparing designs, and surveys were referred to one of the Munich - Western German institutions called Dorsch Consult in 1975 - 1976. Then the General Enterprise updated the design for Sections R/7, 8,10,12,13 in 1981, 1983, 1981, 1981, and 1984 respectively, for State Commission for Roads and Bridges (SCRB) at that time. The Expressway was constructed by international companies with an excellent reputation under the supervision of SCRB. It was designed to provide a design speed of 140 km/h and an axial weight of 16.3 tons. It was divided into two parts and five separate large contracts for each part to facilitate implementation, as follows:

2.3.1 Southern Part

a length of (510) km of 3×3 lanes with a standing lane (15.5m width). The road then splits into a 51-kilometer 2×2 lane to Basra and a 64-kilometer 2×2 lane to Safwan. This part consists of five sections; as shown in Table 1. The southern section includes a 145-kilometer section from Diwaniya to Nasiriya (R6) under construction with Iraqi government funds, it has been in construction on and off for several years, as shown in Figure 1 and Table It starts from the intersection of western Baghdad in (zero-zero)-kilometer to Safwan-Basra interchange, with 1.

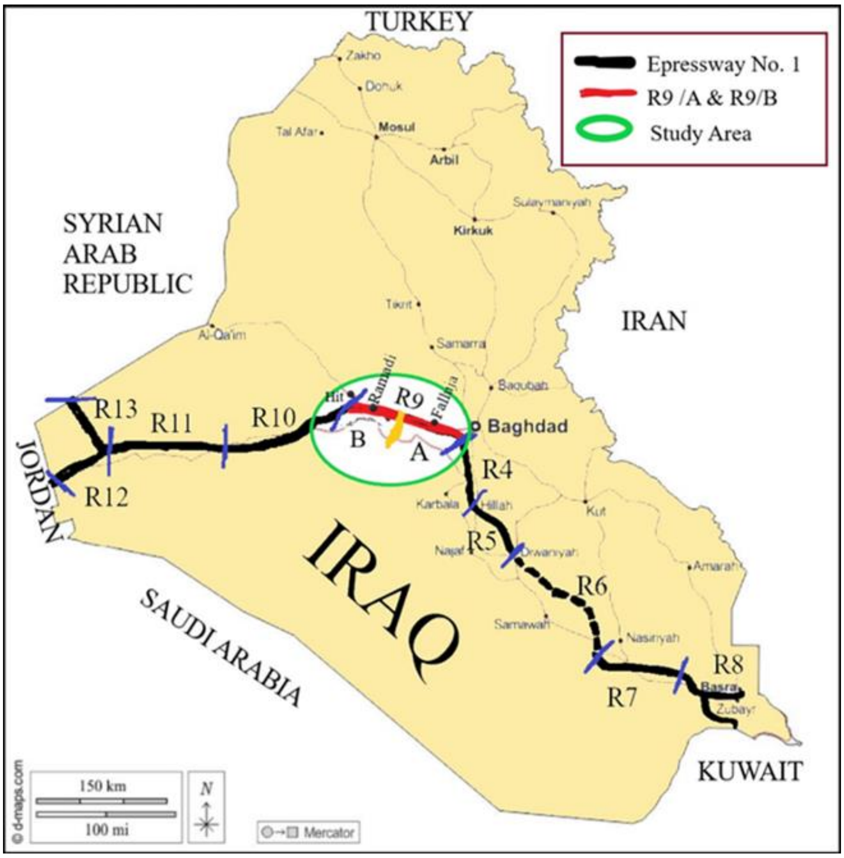


Fig. 1 Map of Iraq showing the path of Expressway No. 1 and location of the study area Section R9

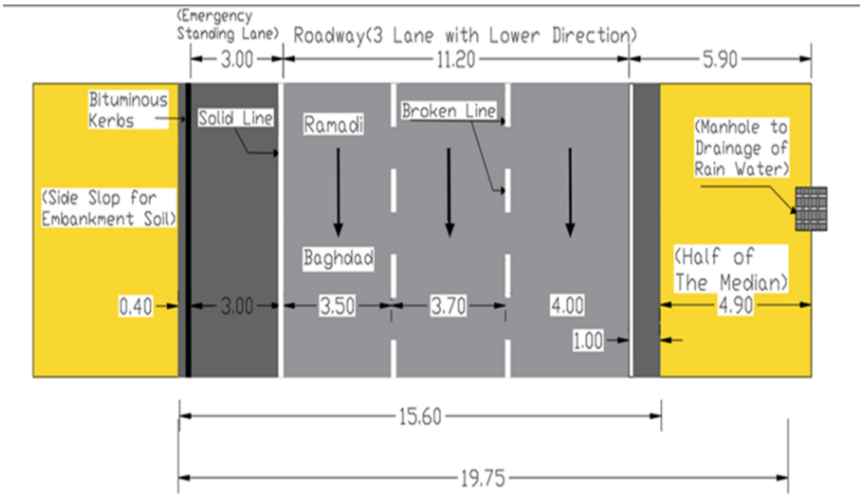
2.3.2 Western part

Starts from the intersection of West Baghdad at a kilometer (zero- zero) towards Anbar Governorate, with a length of (455) km of 3×3 lanes with a standing lane (15.5m width). The road then splits into a 208-kilometer 2×2 lane, from Rutbah to Tribel (Jordanian Border), and from the intersection of H3 to Al Walid (Syrian Border). This part is divided into five sections (IENO FR VO TR C:R/9AB, 1976; Expressway No.1 [internet], 2017; Expressway Directorate, 2017; Madhloom, 2020; & IENO CDR PF C:R/9AB, 1976); as shown in Table 1 and Figure 1.

2.3.3 Section R/9 (Baghdad West – Habbaniya - Ramadi - Hit intersection)

The study area of the current research lies within this section of the expressway (123 km). This section, constructed by Marubini Company- Japanese, was technically divided into R/9A (Baghdad West - Habbaniya), and R/9B (Habbaniya - Ramadi - the intersection of Hit). Each direction of the expressway consists of three lanes as well as a fourth lane for emergency stops. A median strip separates the opposing traffic (IENO CDR PF C: R/9AB, 1976, & IENO CS PT C: R/9AB, 1976), as shown in Figure 2(a) and (b).

(a)



(b)

Fig. 2 Continued: (a) Express No.1 of part R9/A and R9/B (b) Half section.

Table 1- Expressway No.1 Sections

Contract No.	Sections name	Length (km)	Width (m)
	The first Southern Part		
R/4	Baghdad West - Hilla	105	15.5
R/5	Hila - Diwaniya	77	15.5
R/6	Diwaniya - Nasiriya	145	15.5
R/7	Nasiria - Rumaila	145	15.5
R/8A R/8B	Rumaila – Basra Rumaila – Safwan	114	15.5 - 11.75
	The second Western part		
R/9A R/9B	Baghdad West – Habbaniya Habbaniya – Hit	63 61	15.5 15.5
R/10	Hit – Tullaha	129	15.5
R/11	Tullaha – Rutba	137	15.5
R/12	Rutba - Jordanian border	132	11.75
R/13	Jordanian junction (H3) -Syrian border	76	11.75

3. Field Data Collection and Preparation

3.1 Classification of Permeant Deformation

The permanent deformation is a superficial depression in the wheel paths, as shown in Figure 3. The visual field survey of the permanent deformation of the road was carried out in two ways (investigating the depth and density of rutting). Generally, most of the asphalt pavement maintenance processes are related to rutting (Du et al, 2018).

Fig. 3 Measurement of rut depth in the inner and outer wheel tracks of Express No.1 for Station 46+500 in Part R9/A.

In order to determine the proposed maintenance methods of the Rutting for any road and under the relationship between the two classifications as shown in Table 2 (Faraj Allah, 2019; Ammar, 2012); the level of severity (SL) and distress density (DD) must be classified for it.

Table 2 - The proposed maintenance methods for rutting mitigation (after (Faraj Allah, 2019; Ammar, 2012)).

Distress Density (DD) / Severity Level (SL)			1	2	3
			Low	**Medium**	**High**
			D.D. < 10 %	**10% ≤ D.D. ≤ 50%**	**D.D. > 50%**
1	**Low**	6.3 ≤ LS ≤ 12.7 (mm)	Do nothing	Do nothing	Do nothing
2	**Medium**	12.7 ≤ LS ≤ 25.4 mm	Milling and repave	Milling and repave	Milling and repave
3	**High**	LS >25.4 mm	Deep patching	Deep patching	Reconstruction

3.1.1 Classification of Severity Level (SL)

Many highway agencies and researchers have suggested that pavement rutting could lead to vehicle hydroplaning and loss of skid resistance. Most highway agencies classify rut severity based on engineering judgment or field experience. As illustrated in Table 3 (Fwa, & Ong, 2012). previously, there are limits on rut depth thresholds used by different highway agencies in the severity level classification of ruts for pavement maintenance management. Highway Pavement Condition Index (PCI) thresholds will be taken to classify the rutting levels for the study area, as in Table 3 No. 1. For the study area, the severity of rutting was classified into three levels; low, medium, and high as presented in Figure 4 (A, B, and C respectively).

Table 3- Rut severity classification by highway agencies (Fwa, & Ong, 2012)

Highway Agency	Severity levels of rutting		
	Low	**Medium**	**High**
1. Pavement Condition Index (PCI) (Shahin, 1994; Fwa, & Ong, 2012)	0.25-0.5 in.* (6.3-12.7 mm)	0.5-1 in. (12.7-25.4 mm)	>1 in. (>25.4 mm)
2. PASER Manual, Asphalt Roads (Walker et al., 2002; Fwa, & Ong, 2012)	0-0.5 in. (0-12.7 mm)	>1 in. (>25.4 mm)	>2 in. (>50.8 mm)
3. Washington State DOT (WsDOT, 1999; Fwa, & Ong, 2012)	0.25-0.5 in. (6.3-12.7 mm)	0.5-0.75 in. (12.7-19.1 mm)	>0.75 in (>19.1 mm)
4. Ohio DOT (OhDOT, 2006; Fwa, & Ong, 2012)	0.125-0.375 in. (3.2-9.5 mm)	0.375-0.75 in. (9.5-19.1 mm)	>0.75 in. (>19.1 mm)
5. Massachusetts Highway Dept. (CMMPO, 2006; Fwa, & Ong, 2012)	0.25-0.5 in. (6.3-12.7 mm)	0.5-1.5 in. (12.7-38.1 mm)	>1.5 in (>38.1 mm)
6. Ministry of Transportation and Infrastructure, British Columbia (MTI BC, 2009; Fwa, & Ong, 2012)	3-10 mm	10-20 mm	>20 mm

3.1.2 Classification of distress density (DD)

After classifying the study area by severity levels for each section, it is categorized by distress density for each severity level. The density of distress is measured by dividing the area affected by rutting on the total area of the surveyed section multiplied by one hundred. The distress density of rutting was classified into three levels, as in Table 2.

The distress density of the rutting for the study area was also classified into six levels (none, few, intermitted, frequent, extensive, throughout) and according to percent length effected (0, < 10, 10-20, 20-50, 50-80, 80-100) respectively, as shown in Table 4 (MTI BC, 2020). The distress density was calculated for the three sections with a length of 330 m in two ways, either by calculating the percentage of the affected length or the area of the rutting for each section.

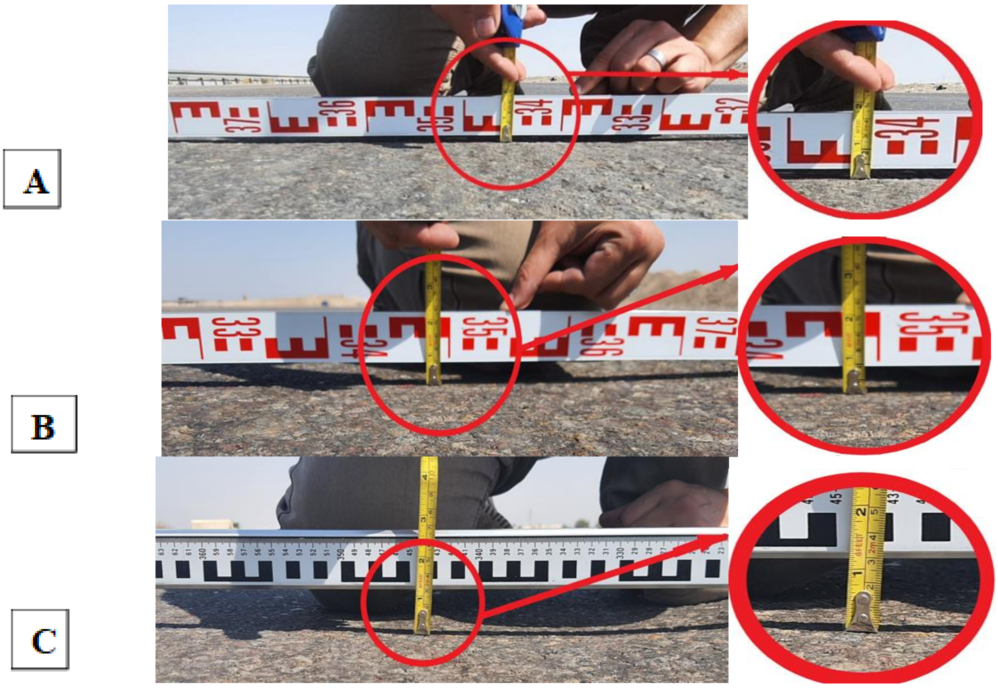


Fig. 4 Severity level measurement: (A) Low for Section 1, (B) Medium for Section 3, (C) High for Section 2.

Table 4 - Level of density (MTI BC, 2020)

Level	Description	Density	Percent length affected
1	None	None	0%
2	Few	Low	<10%
3	Intermittent	Medium	10-20%
4	Frequent		20-50%
5	Extensive	High	50-80%
6	Throughout		80-100%

3.2 Selection of Cross Sections

The field survey of Expressway No. 1 for part R/9 was centered on identifying and classifying ruts based on their severity, see Section 3.1. The study area was surveyed in the following order; see Figure 4 (A, B, and C):

1) One way of the road (down the road) was chosen.
2) Nine subsections of the road were identified with ruts of either high, medium, or low intensity. This was done by
- a sensory field survey, and
- a category vehicle (3 axes, single unit) with 50 tons load to simulate the case of loads on the road.
3) A practical field survey of the nine predetermined sections was conducted by walking using the straight short edge method (SSEM), as shown in Section 3.3.1.
4) Among these stations, only three were selected for measurement of rut directly on the surface of the transverse profile; one with a high rut severity level, one with rut medium severity level and the other with a low rut severity level. These stations are numbered in kilometers and Global Positioning System (GPS), as shown in Table 5.

Table 5 - The locations of the nine stations in the study area.

Station No.	Station (Km)	Length (m)	G.P.S. Position	Part of Express No. 1	Rut Severity
1	04+375	330	33.2920941 N 44.0391002 E	R9/A	Medium
2	15+000	330	33.2866671 N 43.9285374 E	R9/A	Low
3	25+000	330	33.3156566 N 43.8341078 E	R9/A	High
4	34+650	330	33.3899035 N 43.7917047 E	R9/A	Low
5	46+500	330	33.4079433 N 43.6781137 E	R9/A	High
6	50+800	330	33.4380463 N 43.6425706 E	R9/A	Medium
7	54+350	330	33.4502726 N 43.5992254 E	R9/A	Low
8	60+000	330	33.4717171 N 43.5453621 E	R9/A	Medium
9	76+800	330	33.4079433 N 43.6781137 E	R9/B	Medium

3.3 Rutting Measurements

Both static and dynamic methods have been used to measure transverse profile and rut depth. Because of the unavailability of dynamic systems at the present, static methods were used to measure the rut area and depth, which are as follows:

3.3.1 Short Straight Edge Method

The Straight edge method is the most accurate and widely used method by agencies and researchers (Yeganeh1 et al, 2019; Kannemeyer, 1996; Mallela & Wang, 2006; McGhee, 2004; & Wang, 2005). It has been used in this work for rut depth measurement. According to (ASTM-E1703 M , 2010), before taking measurements and collecting data, the pavement surface was cleaned, provided that the pavement surface is free of any obstruction that affects the measurements, for example, potholes or loose debris. Then, a straight metal straightedge with a length of 1.83 meters (6 feet) was used. The straightedge is placed transversely over each path of the wheel in which the rutting occurred; the maximum vertical distance from the bottom of the straight edge to the top surface of the pavement is measured with a gauge and is considered as the rut depth. According to this method, the intensity level of the three stations was determined, as shown in Figure 3, 4 and 5.

Fig. 5 Measuring the rutted level of the three sections using Short Straight Edge Method.

4. Results and Discussion

4.1 Results for Field Data

Each distress type has been classified and rated according to its severity and density. In most cases, there are three levels of severity that describes the condition of the distress with definitions for each level–low, moderate and, high. Furthermore, there are five ranges of density that indicates the portion of the road surface affected by a specific distress type. Photographs and drawings of distress types are provided as a reference for assessing the severity and general mechanisms of failure listed (PSCRM, 2020).

4.1.1 Distress Density

It should be noted that the rut density has been measured in two methods; the first is caudated based on the total length of the section and the lengths of distress in each lane as presented in equation 1.

$$RDD1 = [\Sigma L_r / (2\times L_t)] \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:
RDD1: Distress Density Ratio for the first method
L_r: Length of rut distress in each wheel path of roadway lane (m).
L_t: Total wheel path length of roadway lane (m).

Now the distress intensity for each station is calculated as follows:

$$\left.\begin{aligned} RDD1_{Outer\ lane} &= [(330+330) / (2 \times 330)] \times 100\% = 100\% \\ RDD1_{Middle\ lane} &= [(0+0) / (2 \times 330)] \times 100\% = 0\% \\ RDD1_{Inner\ lane} &= [(330+330) / (2 \times 330)] \times 100\% = 100\% \end{aligned}\right\} \text{for Section 1}$$

$$\left.\begin{aligned} RDD1_{Outer\ lane} &= [(330+330) / (2 \times 330)] \times 100\% = 100\% \\ RDD1_{Middle\ lane} &= [(330+330) / (2 \times 330)] \times 100\% = 100\% \\ RDD1_{Inner\ lane} &= [(0+0) / (2 \times 330)] \times 100\% = 0\% \end{aligned}\right\} \text{for Section 2}$$

$$\left.\begin{aligned} RDD1_{Outer\ lane} &= [(330+330) / (2 \times 330)] \times 100\% = 100\% \\ RDD1_{Middle\ lane} &= [(0+0) / (2 \times 330)] \times 100\% = 0\% \\ RDD1_{Inner\ lane} &= [(330+330) / (2 \times 330)] \times 100\% = 100\% \end{aligned}\right\} \text{for Section 3}$$

Table 6 shows the results of the ratio and level for distress density, description, and comparison with the determinants in Table 4. In addition to the distress density level and comparison with Table 4 of each lane for the three sections. The table also shows the distress density ratio concentrated in lanes (1 and 3) for sections (1 and 3), while in section 2, it is concentrated in lanes (1 and 2). As for lane 2 of Sections (1 and 3) and lane 3 of Section 2, the DD ratio may be zero according to the visual field survey. According to the determinants of Table 4, the density description is none, and the density level of distress is 1; as for the determinants according to Table 2, the density level of the distress is none. Lanes (1 and 3) of Sections (1 and 2) and lanes (1 and 2) of Section 2 have the same results in its affecting the pavement surface. DD ratio is 100% for these lanes. According to the determinants of Table 4, the density description is throughout, and the DD level is 6; for the determinants of Table 2, the density level of distress is high.

Table 6 - Summary of the results of the density and level of distress by method 1.

Section	Lane No.	Distress density (DD) %	Percent length affected	Description	Distress density level	Distress density level	
			(See Table 4)			(See Table 2)	
1	1(Outer)	100	80 - 100	Throughout	6	DD >50%	High
	2(Middle)	0	0	None	1	DD = 0	None
	3(Inner)	100	80 - 100	Throughout	6	DD >50%	High
2	1(Outer)	100	80 - 100	Throughout	6	DD >50%	High
	2(Middle)	100	80 - 100	Throughout	6	DD >50%	High
	3(Inner)	0	0	None	1	DD = 0	None
3	1(Outer)	100	80 - 100	Throughout	6	DD >50%	High
	2(Middle)	0	0	None	1	DD = 0	None
	3(Inner)	100	80 - 100	Throughout	6	DD >50%	High

The second method is based on the relation connecting the area of the rut distress lane and the total section area (MTI BC, 2020). The distress density was calculated for each section of length 330 m and the width of the area affected by rut after dividing the length into periods, each period of length 15. The calculation process is conducted as follows:

$$RDD2 = \Sigma A_r / \Sigma A_{ts} \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where:
RDD2: Distress (rutting) density ratio for the second method,
ΣA_r: The sum of the areas affected by the rut distress (m^2), and
ΣA_{ts}: The total section area (m^2).

$$A_r = D_r \times W_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

where:
D_r: Length of rut distress (m),
W_r: Width of rut distress (m).

$$A_{ts} = D_t \times W_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

where:
D_t: Length of section (m),
W_t: Width of cross-section (m).
An example of calculating the distress density of Section 1 is illustrated as follows:

- $A_{ts(1\text{-}2)} = (15 - 0) \times (14.2+14.2) / 2 = 213\ m^2$

Where:
Sub (1-2): 1 is the start station of first period ; 2 is start station of second period .
$A_{ts(2\text{-}3)} = (30 - 15) \times (14.2+14.2) / 2 = 213\ m^2$
.
.
.
$A_{ts(22\text{-}2)3} = (330 - 315) \times (14.2+14.2) / 2 = 213\ m^2$
$\Sigma A_{ts(1\text{-}23)} = 3696\ m^2$

- $A_{r(1\text{-}2)} = (15 - 0) \times (6.2+6.2) / 2 = 93\ m^2$

$A_{r(2\text{-}3)} = (30 - 15) \times (6.2+6.2) / 2 = 93\ m^2$
.
.
.
$A_{r(22\text{-}23)} = (330 - 315) \times (6.2+6.15) / 2 = 92.625\ m^2$
$\Sigma A_r = 2129.3\ m^2$
$RDD2 = \Sigma A_{r(1\text{-}23)} / \Sigma A_{ts(1\text{-}23)} = 2129.3 / 3696 = 57.610\ \%$
The results of other Sections (2 and 3) were concluded through a similar process, as shown in Table 7, 8, and 9.

Table 7 - Area of distress (rut) density for Section 1 at Station (35+000)

Point No.	period distance points (m)	Roadway Width (Wt) (m)	Roadway Area (Ats) (m2)	Rutting Width (Wr) (m)	Rutting Area (Ar) (m2)	Point No.	period distance points (m)	Roadway Width (Wts) (m)	Roadway Area (Ats) (m2)	Rutting Width (Wr) (m)	Rutting Area (Ar) (m2)
1	0	11.2		6.2		13	180	11.2	168	7.15	109.88
2	15	11.2	168	6.2	93	14	195	11.2	168	6.9	105.38
3	30	11.2	168	6.2	93	15	210	11.2	168	6.7	102
4	45	11.2	168	6.2	93	16	225	11.2	168	6.45	98.625
5	60	11.2	168	6.15	92.625	17	240	11.2	168	6.1	94.125
6	75	11.2	168	6.15	92.25	18	255	11.2	168	6.1	91.5
7	90	11.2	168	6.2	92.625	19	270	11.2	168	6.1	91.5
8	105	11.2	168	6.45	94.875	20	285	11.2	168	6.15	91.875
9	120	11.2	168	6.65	98.25	21	300	11.2	168	6.15	92.25
10	135	11.2	168	6.9	101.63	22	315	11.2	168	6.15	92.25
11	150	11.2	168	7.2	105.75	23	330	11.2	168	6.2	92.625
12	165	11.2	168	7.5	110.25						
Total Area (m2)									3696		2129.3

Table 8 - Area of distress (rut) density for Section 1 at Station (46+800)

Point No.	period distance points (m)	Roadway Width (Wt) (m)	Roadway Area (Ats) (m2)	Rutting Width (Wr) (m)	Rutting Area (Ar) (m2)	Point No.	period distance points (m)	Roadway Width (Wt) (m)	Roadway Area (Ats) (m2)	Rutting Width (Wr) (m)	Rutting Area (Ar) (m2)
1	0	11.2		8.85		13	180	11.2	168	9.2	138.375
2	15	11.2	168	8.85	132.75	14	195	11.2	168	9.2	138
3	30	11.2	168	8.9	133.13	15	210	11.2	168	9.2	138
4	45	11.2	168	8.9	133.5	16	225	11.2	168	9.15	137.625
5	60	11.2	168	8.9	133.5	17	240	11.2	168	9.15	137.25
6	75	11.2	168	8.9	133.5	18	255	11.2	168	9.15	137.25
7	90	11.2	168	8.95	133.88	19	270	11.2	168	9	136.125
8	105	11.2	168	8.95	134.25	20	285	11.2	168	9	135
9	120	11.2	168	9.1	135.38	21	300	11.2	168	9	135
10	135	11.2	168	9.2	137.25	22	315	11.2	168	9.1	135.75
11	150	11.2	168	9.2	138	23	330	11.2	168	8.9	135
12	165	11.2	168	9.25	138.38						
Total Area (m2)									3696		2986.88

Table 9 - Area of distress (rut) density for Section 1 at Station (76+800)

Point No.	period distance points (m)	Roadway Width (Wt) (m)	Roadway Area (Ats) (m2)	Rutting Width (Wr) (m)	Rutting Area (Ar) (m2)	Point No.	period distance points (m)	Roadway Width (Wt) (m)	Roadway Area (Ats) (m2)	Rutting Width (Wr) (m)	Rutting Area (Ar) (m2)
1	0	11.2		6.8		13	180	11.2	168	7.8	118.5
2	15	11.2	168	6.8	102	14	195	11.2	168	7.7	116.25
3	30	11.2	168	6.9	102.75	15	210	11.2	168	7.5	114
4	45	11.2	168	6.9	103.5	16	225	11.2	168	7.35	111.375
5	60	11.2	168	7.1	105	17	240	11.2	168	7.1	108.375
6	75	11.2	168	7.15	106.88	18	255	11.2	168	7.1	106.5
7	90	11.2	168	7.35	108.75	19	270	11.2	168	7	105.75
8	105	11.2	168	7.5	111.38	20	285	11.2	168	7	105
9	120	11.2	168	7.65	113.63	21	300	11.2	168	7	105
10	135	11.2	168	7.8	115.88	22	315	11.2	168	6.8	103.5
11	150	11.2	168	8	118.5	23	330	11.2	168	6.7	101.25
12	165	11.2	168	8	120						
Total Area (m2)									3696		2403.75

The final results in Tables 7, 8, and 9 for three sections are presented in Table 10.

Table 10 - Summary of the results of roadway area, Rutting area, and the density distress method 2.

Section	Roadway area (m2)	Rutting area (m2)	Distress (rut) density %
1	3696	2129.3	57.61
2	3696	2986.88	80.82
3	3696	2403.75	65.1

From Tables 2 and 10, the level of distress density for three sections is determined as shown in Table 11.

Table 11 - Summary of the results of the density and level of distress by method 2.

Section	Distress density %	Percent length affected	Description (See Table 4)	Distress density level	Distress density level (See Table 2)	
1	57.61	50 - 80	Extensive	5	D.D. >50%	High
2	80.82	80 - 100	Throughout	6	D.D. >50%	High
3	65.1	50 -80	Extensive	5	D.D. >50%	High

As presented in Table 11, the distress density of three sections are described as follows:

1. Section 1: according to the results, the distress density is 57.61%, representing the section's distress density ratio. Therefore, this section can be considered as it has less rutting compared to the two sections. Moreover, according to the classification, the type of distress is Extensive as it is within the 50-80% range. This, in fact, agrees with what has been observed on the site.
2. Section 2: the distress density is 80.82%, therefore the rutting is distributed in all directions. Therefore, this section can be considered as it has more rutting compared to that of the two sections. Moreover, according to the classification, the type of distress is Throughout as it is within the range of 80-100%. This agrees with visual vision.
3. Section 3: the distress density is 65.1%, therefore it is higher than Section 1 and more damage than Section 1. Moreover, according to the classification, the type of distress is throughout as it is within the range of 50 -80%. The classification of this section is Extensive.
4. According to the two methods applied, as shown in Table 6 and Table 11, it was noted that the distress intensity level is 6, 5, and high.

4.1.2 Severity Level

After visual scanning for the surfaces of the three sections by the walk-on site and rutting classification is available according to the classification specification. The survey includes measuring the depth of the rutting with a length of 330 meters at intervals of 15 meters for each the lane in section, as shown in Table 12. The results of Table 12 for the three stations can be summarized as shown in Table 13. According to the results, the average rutting depth for lanes 1, 3, outer and inner for Section 1 represents a low level of rutting. Therefore, this section has less rutting than the other two sections. As for the average rutting depth for lanes 1 and 2, outer and inner, Section 2 represents a high level for rutting, except for the inner lane 2, which has a medium level of risk. Therefore, this section is more rutting compared to the other two sections. Finally, the average rutting depth for lanes 1 and 3, outer and inner, for Section 3 represents the medium level of rutting. Therefore, this section has less rutting than section 2 and more rutting than Section 1, compared to the other two sections. It is consistent with what was noticed on the site.

Table 12 - Distress survey (Rutting) for Pavements with Asphalt Concrete Surfaces: (A-1) - (A-2) for Section 1, (B-1) - (B-2) for Section 2, and (C-1) - (C-2) for Section 3.

(A-1) for Section 1

Outer Wheel Path for lane 1						Inner Wheel Path for lane 1					
Point No.	Point Distance (m)	Rut Depth (mm)	Point No.	Point Distance (m)	Rut Depth (mm)	Point No.	Point Distance (m)	Rut Depth (mm)	Point No.	Point Distance (m)	Rut Depth (mm)
1	0.00	5	13	180	7	1	0.00	5	13	180	3
2	15	10	14	195	7	2	15	10	14	195	4
3	30	10	15	210	8	3	30	10	15	210	6
4	45	13	16	225	11	4	45	12	16	225	8
5	60	8	17	240	7	5	60	8	17	240	9
6	75	13	18	255	9	6	75	13	18	255	6
7	90	13	19	270	13	7	90	10	19	270	4
8	105	11	20	285	11	8	105	11	20	285	12
9	120	11	21	300	13	9	120	5	21	300	12
10	135	3	22	315	10	10	135	2	22	315	9
11	150	5	23	330	11	11	150	2	23	330	9

12	165	8			
				Ave. Rutting	9.435
Outer Rutting → (6.3 < 9.43< 13) mm → Low severity level					

12	165	7			
				Ave. Rutting	7.70
Inner Rutting → (6.3 < 7.70 < 12.7) mm → Low severity level					

(A-2) for Section 1

Point No.	Point Distance (m)	Rut Depth (mm)	Point No.	Point Distance (m)	Rut Depth (mm)
1	0.00	5	13	180	7
2	15	9	14	195	6
3	30	10	15	210	8
4	45	11	16	225	8
5	60	9	17	240	7
6	75	11	18	255	8
7	90	12	19	270	10
8	105	10	20	285	11
9	120	11	21	300	11
10	135	5	22	315	9
11	150	6	23	330	9
12	165	7			
				Ave. Rutting	8.7
Outer Rutting → (6.3 < 8.7 < 12.7) mm → Low severity level					

Point No.	Point Distance (m)	Rut Depth (mm)	Point No.	Point Distance (m)	Rut Depth (mm)
1	0.00	5	13	180	3
2	15	9	14	195	5
3	30	9	15	210	5
4	45	10	16	225	6
5	60	7	17	240	9
6	75	10	18	255	5
7	90	8	19	270	4
8	105	10	20	285	10
9	120	5	21	300	11
10	135	3	22	315	8
11	150	2	23	330	7
12	165	6			
				Ave. Rutting	6.83
Inner Rutting → (6.3 < 6.83 < 12.7) mm → Low severity level					

(B-1) for Section 2

Outer Wheel Path for lane 1					
Point No.	Point Distance (m)	Rut Depth (mm)	Point No.	Point Distance (m)	Rut Depth (mm)
1	0.00	20	13	180	32
2	15	16	14	195	37
3	30	22	15	210	35
4	45	30	16	225	27
5	60	27	17	240	23
6	75	28	18	255	30
7	90	32	19	270	34
8	105	31	20	285	37
9	120	33	21	300	35
10	135	40	22	315	35
11	150	40	23	330	37
12	165	35			
				Ave. Rutting	31.13
Outer Rutting → (31.13 > 25.4) mm → High severity level.					

Inner Wheel Path for lane 1					
Point No.	Point Distance (m)	Rut Depth (mm)	Point No.	Point Distance (m)	Rut Depth (mm)
1	0.00	20	13	180	27
2	15	16	14	195	37
3	30	20	15	210	30
4	45	22	16	225	20
5	60	21	17	240	21
6	75	22	18	255	26
7	90	25	19	270	25
8	105	22	20	285	30
9	120	27	21	300	27
10	135	33	22	315	33
11	150	27	23	330	28
12	165	32			
				Ave. Rutting	25.696
Inner Rutting → (25.7 > 25.4) mm → High severity level.					

(B-2) for Section 2

Outer Wheel Path for lane 2					
Point No.	Point Distance (m)	Rut Depth (mm)	Point No.	Point Distance (m)	Rut Depth (mm)
1	0.00	18	13	180	30
2	15	15	14	195	33
3	30	20	15	210	3
4	45	27	16	225	25

Inner Wheel Path for lane 2					
Point No.	Point Distance (m)	Rut Depth (mm)	Point No.	Point Distance (m)	Rut Depth (mm)
1	0.00	20	13	180	26
2	15	15	14	195	35
3	30	18	15	210	30
4	45	20	16	225	22

5	60	26	17	240	20
6	75	28	18	255	36
7	90	30	19	270	30
8	105	27	20	285	34
9	120	29	21	300	34
10	135	37	22	315	32
11	150	36	23	330	34
12	165	34			
			Ave. Rutting		27.74
Outer Rutting → (27.74 ≥ 25.4) mm → High severity level.					

5	60	20	17	240	19
6	75	19	18	255	23
7	90	24	19	270	26
8	105	21	20	285	30
9	120	25	21	300	25
10	135	32	22	315	30
11	150	27	23	330	26
12	165	33			
			Ave. Rutting		24.609
Inner Rutting → (12.7 ≤ 24.61 < 25.4) mm → Medium severity level.					

(C-1) for Section 3

Outer Wheel Path for lane 1					
Point No.	**Point Distance (m)**	**Rut Depth (mm)**	**Point No.**	**Point Distance (m)**	**Rut Depth (mm)**
1	0.00	22	13	180	19
2	15	20	14	195	20
3	30	16	15	210	17
4	45	18	16	225	19
5	60	15	17	240	21
6	75	20	18	255	18
7	90	15	19	270	18
8	105	18	20	285	17
9	120	20	21	300	20
10	135	12	22	315	22
11	150	20	23	330	19
12	165	18			
			Ave. Rutting		31.13
Outer Rutting → (12.7 ≤ 18.43 < 25.4) mm → Medium severity level.					

Inner Wheel Path for lane 1					
Point No.	**Point Distance (m)**	**Rut Depth (mm)**	**Point No.**	**Point Distance (m)**	**Rut Depth (mm)**
1	0.00	18	13	180	15
2	15	18	14	195	16
3	30	12	15	210	13
4	45	15	16	225	16
5	60	12	17	240	19
6	75	17	18	255	15
7	90	12	19	270	15
8	105	15	20	285	12
9	120	16	21	300	17
10	135	10	22	315	18
11	150	17	23	330	15
12	165	13			
			Ave. Rutting		15.04
Inner Rutting → (12.7 ≤ 15.04 < 25.4) mm → Medium severity level.					

(C-2) for Section 3

Outer Wheel Path for lane 3					
Point No.	**Point Distance (m)**	**Rut Depth (mm)**	**Point No.**	**Point Distance (m)**	**Rut Depth (mm)**
1	0.00	22	13	180	19
2	15	18	14	195	17
3	30	16	15	210	14
4	45	17	16	225	18
5	60	15	17	240	19
6	75	17	18	255	15
7	90	13	19	270	16
8	105	18	20	285	17
9	120	18	21	300	21
10	135	14	22	315	19
11	150	19	23	330	16
12	165	17			
			Ave. Rutting		17.17
Outer Rutting → (12.7 ≤ 17.17 < 25.4) mm → Medium severity level.					

Inner Wheel Path for lane 3					
Point No.	**Point Distance (m)**	**Rut Depth**	**Point No.**	**Point Distance (m)**	**Rut Depth (mm)**
1	0.00	18	13	180	12
2	15	16	14	195	14
3	30	10	15	210	12
4	45	14	16	225	13
5	60	11	17	240	16
6	75	15	18	255	15
7	90	10	19	270	13
8	105	13	20	285	11
9	120	14	21	300	16
10	135	10	22	315	16
11	150	15	23	330	15
12	165	12			
			Ave. Rutting		13.52
Inner Rutting → (12.7 ≤ 13.52 < 25.4) mm → Medium severity level.					

Table 13 - Summary of the results of the Severity level of rutting for each lane in Sections 1, 2, and 3.

Station	Lane	Wheel Path	Ave. Rutting depth, mm	(Shahin, 1994) [7,8], mm	Severity levels
1	1	Outer	9.43	6.3 – 12.7	Low
		Inner	7.74	6.3 – 12.7	
	2	Outer	-	-	-
		Inner	-	-	
	3	Outer	8.7	6.3 – 12.7	Low
		Inner	6.83	6.3 – 12.7	
2	1	Outer	31.13	> 25.4	High
		Inner	25.7	> 25.4	
	2	Outer	27.74	> 25.4	High
		Inner	24.61	12.7 - 25.4	Medium
	3	Outer	-	-	-
		Inner	-	-	
3	1	Outer	18.43	12.7 - 25.4	Medium
		Inner	15.04	12.7 - 25.4	
	2	Outer	-	-	-
		Inner	-	-	
	3	Outer	17.17	12.7 - 25.4	Medium
		Inner	13.52	12.7 - 25.4	

The results of Table 12 for the three stations can be summarized as shown in Table 13. According to the results, the average rutting depth for outer and inner wheel path of outer and inner lanes for Section 1, represents a low level of rutting. Therefore, this section is less rutting than the other two sections. As for the average rutting depth outer and inner wheel path of outer and the middle lanes for Section 2 represents a high level for rutting, except for the internal side of the middle lane, which has a medium level of risk. Therefore, this section has more rutting compared to the other two sections. Finally, the average rutting depth outer and inner wheel path of outer and inner lanes for Section 3 represents the medium level of rutting. Therefore, this section has less rutting than section 2 and more rutting than Section 1 compared to the other two sections. It is consistent with what was noted on the site.

4.1.3 Maintenance methods

The maintenance method is selected based on the relations connected between the distress density and the severity level of rutting as illustrated in Tables 6, 11, and 13 for the three sections and according to the classification presented in Table 2.

Table 14 shows the relation between the distress density and severity level of rutting as well as the required type of maintenance, which should be applied in the three sections. According to the results, it was highlighted that there was no requirement (Do nothing) for any maintenance in the first section and there is no effect on the traffic flow or safety. In contrast, there is a Reconstruction requirement for the whole asphalt layers 1, 2, and 3 of section two as there is a high danger affecting traffic flow, especially at high levels of speed. However, section three requires only Milling and re-paving the asphalt layers 1 and 2 which have rutting.

Table 14 - The proposed maintenance methods for rutting mitigation

	Station	1	2	3
Station	(DD) / (SL)	High	High	High
1	Low	Do nothing	---	---
2	High	---	Reconstruction	---
3	Medium	---	---	Milling and repave

5. Conclusion

5.1 The field survey

Inspection of the field survey results indicates that pavement rutting generally covers most of the Expressway No.1 sections under consideration. In most cases, high severity levels of rutting were recorded, particularly at checkpoints and intersections.

5.2 Distress density and severity level

The field survey showed that the damage density level varies spatially according to the location of the lane with respect to the outer edge of the expressway, i.e.

1. The damage density level in lane 1 was always high (> 50%) but with different severity levels. This may be attributed to the fact that the lane is typically specified for heavy duty and slow vehicles according.
2. The damage density level in lane 2 of Section 2 was always high (> 50%) with high severity levels. The curved geometry of this section (near Saqlawiah City) may have contributed to this rutting characteristic where drivers tend to use the outer lanes 1 and 2 rather than lane 3.
3. The damage density level in lane 3 of Sections 1 and 3 was always high (> 50%) with low and medium severity levels, respectively. These sections are generally straight, leading to heavy load concentration on lane 1 and lightweight concentration on lane 3.
4. It was observed that the outer wheel path of each lane has generally higher severity levels than the inner wheel path.

5.3 Maintenance opportunities to Expressway No.1

Based on the recommendation given in Section 3.1.3, and based on the calculated values of distress density and severity level (see Section 3.1.1 and 3.1.2), it is recommended that:

a) Doing nothing to Section 1 owing to the small values of damage density and severity levels,
b) Reconstructing the asphaltic layers 1, 2 and 3 and re-compacting the subbase layer 4 in Section 2, owing to the large values of damage density and severity levels, and
c) Milling and repaving the asphaltic layers 1, 2.

5.4 Maintenance and preventive strategies

1. It is recommended to repair all the distresses in Expressway No.1as soon as possible to avoid further maintenance costs.
2. It is recommended to move all the checkpoints outside the expressway.
3. Installing weigh station along the expressway to check and control heavy trucks weights.
4. Regular inspection of the expressway and preforming regular preventive measures.
5. Developing a modern pavement management system for the expressways in Iraq.
6. The work of permanent committees of engineers with high experience in the field of road engineering from the relevant institutions, while providing them with all the necessary requirements to follow up on Expressway No.1 on an ongoing basis and submit a work report to its institutions.

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